

Ultra-low phase noise optical pulses generated by coupled opto-electronic oscillator

Ertan Salik, Nan Yu, and Lute Maleki

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, California 91109
ertan.salik@jpl.nasa.gov

Abstract: An EDFA-based coupled opto-electronic oscillator (COEO) can generate ultra-low noise optical pulses and microwave signals. The phase noise of the COEO is lower than -135 dBc/Hz at 10 kHz away from a 10 GHz carrier.

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The coupled opto-electronic oscillator [1] is an integrated optical and microwave device capable of generating low time jitter optical pulses and ultra-low phase noise microwave signals for optical communications, optical analog-to-digital conversion, and radar applications.

The COEO (Fig. 1) is a combination of the optoelectronic oscillator (OEO) [5], and an optical source in the loop that functions as a modelocked laser (MLL) [6,7]. The OEO converts CW light energy into low-noise microwave signals using a photonic high-Q element, usually a long piece of fiber [5]. For oscillation, both the OEO and COEO need gain in the optoelectronic loop; in addition the COEO requires one of the laser mode beat frequencies to coincide with one of the optoelectronic oscillator modes [1]. The microwave filter determines the microwave oscillation frequency, and the optical filter selects the optical band. Here, the OEO segment generates the low-phase noise microwave signal, which also drives the MLL for low-jitter optical pulses.

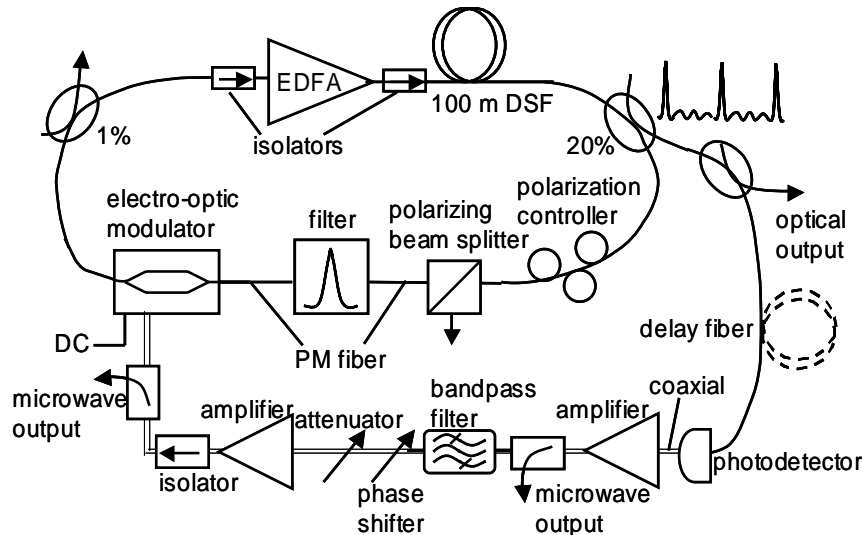


Fig. 1. Schematic of coupled opto-electronic oscillator (COEO). COEO is combination of opto-electronic oscillator and mode-locked laser.

We obtained nearly transform-limited sech^2 optical pulses of 4.1 ps (FWHM) duration, and 80 GHz bandwidth. The EDFA output power was 14 dBm (25 mW), and the loop loss was ~11 dB. The total dispersion for the optical loop was 0.19 ps/nm. This system operates stably for hours at a time without any external stabilization.

Because phase noise measurement of the ultra-low noise oscillators require very stable, rarely available reference oscillators, we use the frequency discriminator method [8] with 1-20 km-long optical

fiber as the delay line, where no phase locking is needed. However, a long length of fiber limits the upper frequency range measurable, and has degraded performance with low frequency noise due to vibrational and thermal instability. The phase noise measurement of the COEO and a commercial synthesizer (HP 8761A) is shown in Fig. 2. With nearly $1/f^3$ behavior in the entire range, phase noise is -135 dBc/Hz at 10 kHz offset. This is among the lowest noise reported for similar actively modelocked laser systems [2-4], and without any additional low phase noise external source.

A cross-correlation measurement [9,10] demonstrated that the amplifier noise is not a limit. In 1-10 kHz range, Fig. 2 shows the noise floor as overlapping with the phase noise. We measured the amplitude (AM) noise 10 dB higher than the phase noise floor. We conclude that the AM noise sets the limit, and we are currently in the process of suppressing it.

We observe some excess noise at $f < 1$ kHz with 4.46 km fiber, and measured 10 dB higher noise with a fiber of exact same length, but higher dispersion. Our conclusion is that the fiber adds noise, and further investigation will show the actual phase noise, which is evidently even lower.

We have demonstrated an ultra-stable COEO with phase noise lower than -135 dBc/Hz at 10 kHz offset frequency and correspondingly low jitter, which is our. Currently we are exploring approaches to suppress the amplitude noise, and eliminate the fiber noise in the measurement system to measure the actual phase noise of the oscillator.

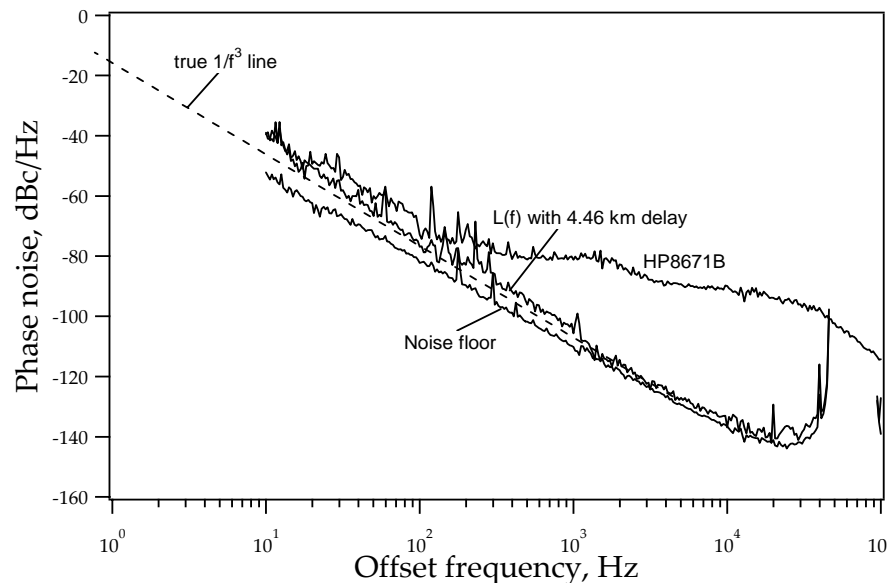


Fig. 2. Phase noise of COEO measured by frequency discriminator method using 4.46 km of fiber with 4.5 ps/nm/km dispersion. Phase noise is better than -135 dBc/Hz at 10 kHz away from the carrier, and has a $1/f^3$ behaviour up to 20 kHz offset frequency, our measurement limit.

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